RECOVERING RELATIVISTIC NUCLEAR PHENOMENOLOGY FROM THE QUARK-MESON COUPLING MODEL

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The quark-meson coupling (QMC) model for nuclear matter, which describes nuclear matter as non-overlapping MIT bags bound by the self-consistent exchange of scalar and vector mesons is modified by the introduction of a density dependent bag constant. It is found that when the bag constant is significantly reduced in nuclear medium with respect to its free space value, large canceling isoscalar Lorentz scalar and vector potentials for the nucleon in nuclear matter emerge naturally. Such potentials are comparable to those suggested by relativistic nuclear phenomenology. This suggests that the modification of the bag constant in the nuclear medium may play an important role in low- and medium-energy nuclear physics.

While the description of nuclear phenomena has been efficiently formulated using the hadronic degrees of freedom, new challenges arise from the observed small but interesting corrections to the standard hadronic picture such as the EMC effect which reveals the medium modification of the internal structure of nucleon. To address these new challenges, it is necessary to build theories that incorporate quark-gluon degrees of freedom, yet respect the established theories based on hadronic degrees of freedom.

A few years ago, Guichon[1] proposed a quark-meson coupling (QMC) model to investigate the direct "quark effects" in nuclei. This model describes nuclear matter as non-overlapping MIT bags interacting through the self-consistent exchange of mesons in the mean-field approximation [1,2]. The QMC model, however, predicts much smaller scalar and vector potentials for the nucleon than obtained in relativistic nuclear phenomenology. The latter is a general approach based on nucleons and mesons which has gained tremendous credibility during last twenty years[3]. It is known that the large and canceling scalar and vector potentials are central to the success of the relativistic nuclear phenomenology.

We observe that the bag constant is held to be at its free space value in the QMC model. This assumption can be questioned. The bag constant in the MIT bag model contributes $\sim 200-300$ MeV to the nucleon energy and provides the necessary pressure to confine the quarks. Thus, the bag constant is an inseparable ingredient of the bag picture of a nucleon. When a nucleon bag is put into the nuclear medium, the bag as a whole reacts to the environment.

As a result, the bag constant may be modified. There is little doubt that at sufficiently high densities, the bag constant is eventually melted away and quarks and gluons become the appropriate degrees of freedom. Therefore, It is reasonable to believe that the bag constant is modified and decreases as density increases. This physics is obviously bypassed in the QMC model by the assumption of $B = B_0$ [1,2].

We modify the QMC model by introducing a density dependent bag constant. We model the density dependence of the bag constant in two ways: one invokes a direct coupling of the bag constant to the scalar meson field, and the other relates the bag constant to the in-medium nucleon mass [4]. Both models feature a decreasing bag constant with increasing density. We find that the reduction of the bag constant in nuclear matter partially offsets the effect of the internal quark structure of the nucleon and effectively introduces a new source of attraction. This attraction needs to be compensated with additional vector field strength. The decrease of bag constant also implies the increase of bag radius in nuclear matter. This is consistent with the "swollen" nucleon picture discussed in the literature.

When the bag constant is reduced significantly in nuclear matter with respect to its free-space value, we find that our modified quark-meson coupling model predicts large and canceling scalar and vector potentials for the nucleon in nuclear matter, which is qualitatively different from the prediction of the simple QMC model. These potentials are consistent with those suggested by the relativistic nuclear phenomenology, implying that the essential physics of the relativistic nuclear phenomenology can be recovered. This suggests that the drop of the bag constant in nuclear medium may play an important role in low- and medium-energy nuclear physics.

Acknowledgments

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References

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